



## MABEL Iceland 2012

### Flight Report

*William B. Cook, Kelly M. Brunt, Eugenia L. DeMarco, Daniel L. Reed, Thomas A. Neumann, Thorsten Markus*



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### **Abstract**

In March and April 2012, NASA conducted an airborne lidar campaign based out of Keflavik, Iceland, in support of Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) algorithm development. The survey targeted the Greenland Ice Sheet, Iceland ice caps, and sea ice in the Arctic Ocean during the winter season. Ultimately, the mission, *MABEL Iceland 2012*, including checkout and transit flights, conducted 14 science flights, for a total of over 80 flight hours over glaciers, icefields, and sea ice.



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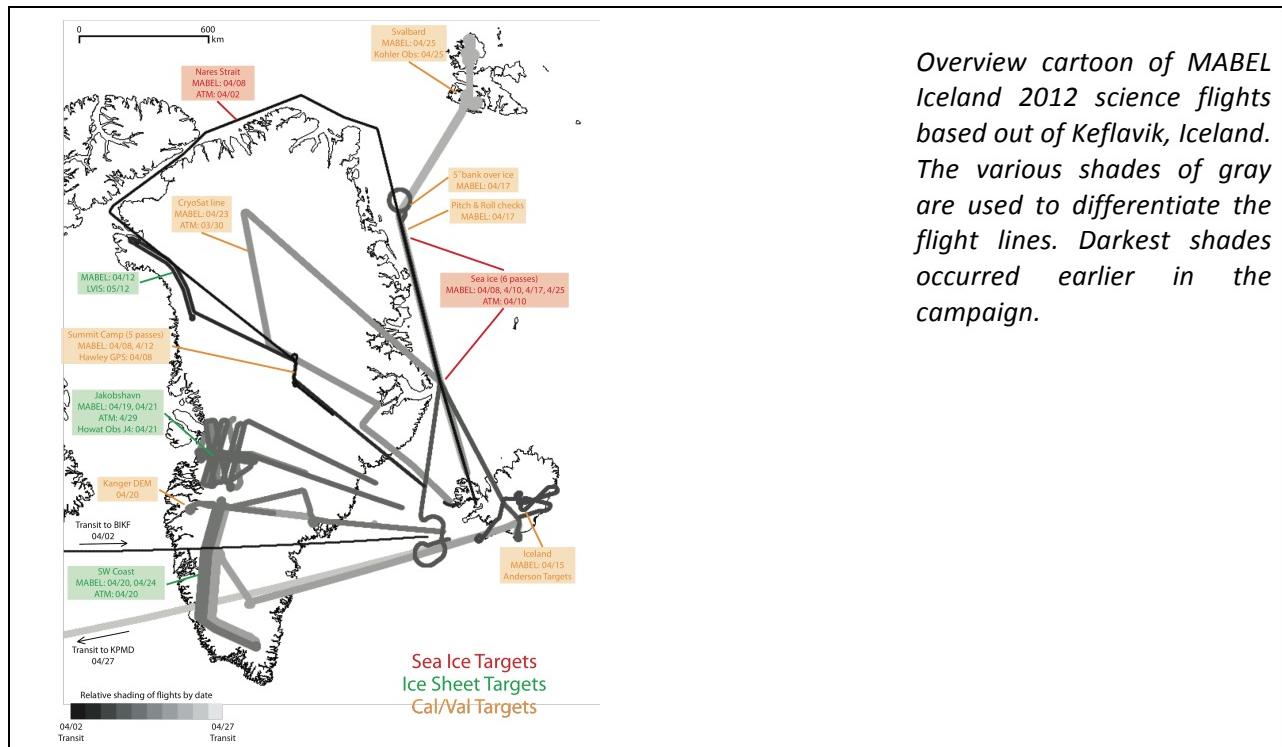
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## Introduction

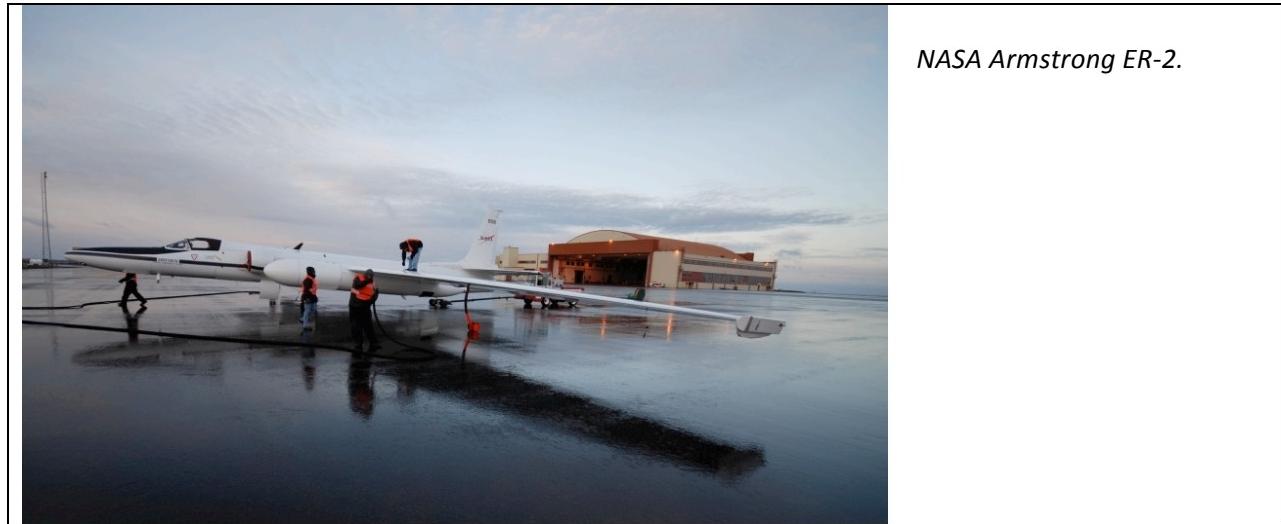
In support of Ice, Cloud, and land Elevation Satellitee 2 (ICESat 2; Markus et al., 2017), NASA has conducted a series of airborne campaigns primarily to enable the development of ICESat-2 geophysical algorithms prior to launch, which is scheduled for late 2017. ICESat-2 will carry the Advanced Topographic Laser Altimeter System (ATLAS), which will be a six-beam photon-counting laser altimeter using 532-nm wavelength pulses. Given this new approach to satellite surface elevation measurement, a series of airborne lidar campaigns were designed to: 1) enable the development of ICESat-2 geophysical algorithms prior to launch; 2) enable ICESat-2 error analysis; and 3) provide ATLAS model validation.

The primary airborne instrument used for algorithm development has been the Multiple Altimeter Beam Experimental Lidar (MABEL; McGill et al., 2013). Bill Cook is the MABEL Principal Investigator. MABEL is a photon-counting multibeam lidar sampling at both 532- and 1064-nm wavelengths. Previous airborne MABEL campaigns have included a series of engineering flights high-altitude aircraft based out of California (2010, 2011, and 2012). Other campaigns were designed to address specific science goals with targets that included vegetation ‘leaf-on’ conditions (based in Wallops Island, Virginia, September 2012 and Hampton, Virginia, September 2013) and summer land ice and sea ice conditions, based out of Fairbanks, Iceland 2012 (Brunt et al., 2016). A major campaign based in Keflaik, Iceland, in March and April 2012, was intended to sample ice sheets and sea ice in winter conditions (Brunt et al., 2014; Kwok et al., 2014; Farrell et al., 2015). This campaign has thus far provided the bulk of the data used to generate the ATLAS onboard algorithms. The mission, *MABEL Iceland 2012*, was based out of Keflavik, Iceland. Ultimately 14 science flights were conducted, for a total of over 80 flight hours over the glaciers, ice caps, and sea ice.



## Instrumentation and Aircraft

MABEL is optimized for high-altitude sampling (above 15 km) with a goal of sampling at about 20 km, or above more than 90% of the atmosphere. To accomplish this, MABEL has been deployed on 2 high-altitude aircraft: the NASA Armstrong ER-2 and the Scaled Composites Protues. For the Iceland 2012 deployment, MABEL was integrated into the nosecone of the ER-2 in July 2014. Flights with this aircraft were planned at about 7 to 8 hours, including takeoff and decent; data collection totaled about 6 to 7 hours per flight.



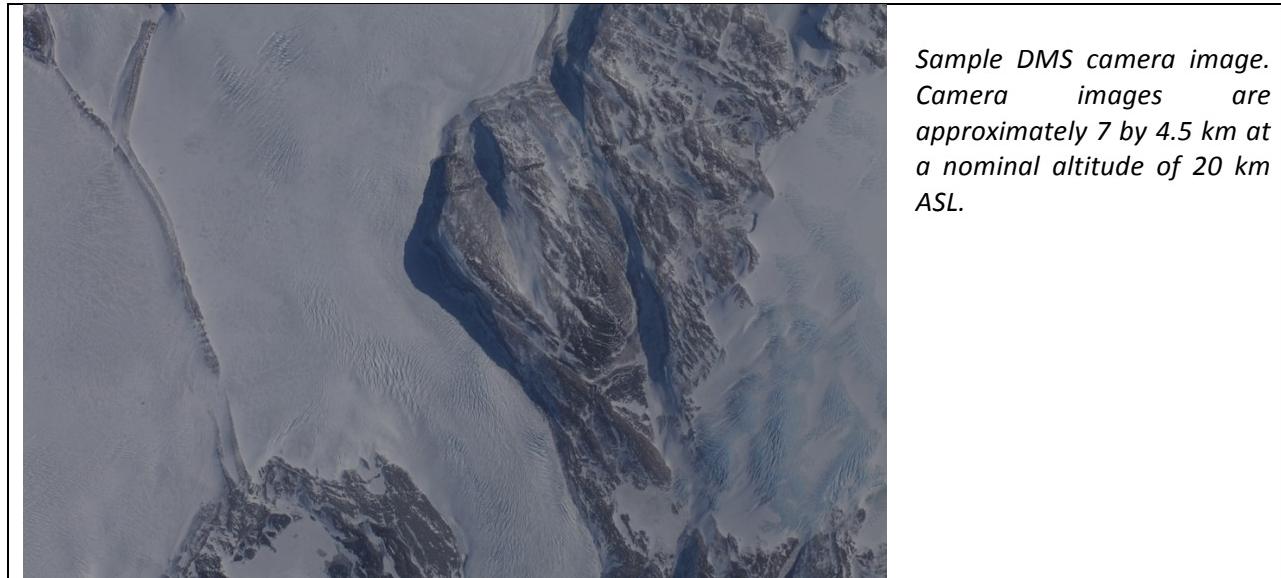
*NASA Armstrong ER-2.*

MABEL has beams at both 532 (green) and 1064 (near infrared) nm wavelengths. MABEL has as many as 16 green beams and as many as 8 near infrared beams. For the Iceland 2012 campaign, instrumentation issues limited MABEL to 13 green beams and 4 near infrared beams. MABEL beams are arranged in a linear array, perpendicular to the direction of flight. The system allows for beam-geometry changes between flights with a maximum view angle of  $\pm 1$  km from a 20-km nominal altitude. For the Iceland 2012 campaign, the maximum across-track beam spacing was 200 m. The repetition rate of MABEL is variable (between 5 and 25 kHz); the Iceland 2012 campaign used 5 kHz. At this nominal altitude, repetition rate, and an aircraft speed of  $\sim 200$  m/s, MABEL samples a  $\sim 2$ -m footprint every  $\sim 4$  cm along track.

Ancillary instrumentation on the NASA ER-2 included Cloud Physics Lidar (CPL). Matt McGill is the CPL Principal Investigator. CPL is a 3-wavelength lidar (355, 532, and 1064 nm) for atmospheric applications with 30 m vertical resolution. Processed CPL is key for atmospheric validation of processed MABEL data. Further, real-time quick-look imagery telemetered from CPL provides an assessment of what MABEL is sampling in real-time.

For the Iceland 2012 campaign, 2 camera systems were deployed in a separate part of the aircraft, relative to MABEL. The NASA ER-2 Cirrus Digital Camera System (DCS) and Digital Mapping System (DMS) were deployed in the main body of the ER-2 (Cube A). The DCS camera system is a 16-megapixel Hasselblad 555ELD color digital camera (Elvidge et al., 2007) with a 150 mm lens from Zeiss optics with a 26° field of view. It produces a 4072 x 4072 pixel image; at a nominal altitude of 20 km ASL, it produces a total swath of  $\sim 5$  km and a  $\sim 1.2$  m nominal pixel resolution. The 150 mm lens had not been deployed on

the ER-2 prior to this deployment. Therefore, a backup camera system was also deployed. The DMS was integrated next to DCS; for this deployment, it had an 85 mm lens. It produces a 5616 x 3744 pixel image; at a nominal altitude of 20 km ASL, it produces a total swath of ~7 by 4.5 km and a ~1.2 m nominal pixel resolution.



*Sample DMS camera image. Camera images are approximately 7 by 4.5 km at a nominal altitude of 20 km ASL.*

## **Discussion and Conclusions**

The appendix of this document includes summaries associated with each individual mission flight. Details captured in these summaries include maps of flight tracks, comments about the instrumentation, and comments about weather.

MABEL requires clear sky conditions for sampling. This deployment experienced excellent weather conditions and phenomenal weather prediction support from the Icelandic Met Office. The flight summaries make note of the general weather conditions.

A MABEL instrument checkout flight was conducted based out of Palmdale, California, and included targets over vegetated regions. When MABEL transited from Palmdale, California to Keflavik, Iceland, the flight included a gaged reservoir (Fort Peck) in Montana.

For land ice surveys, to address the science goals, a major flight objective was to acquire MABEL data over winter ice sheet conditions. Coordination with the science support staff at Summit Station, Greenland led to *in situ* GPS measurements for direct comparison with MABEL elevation data. For sea ice surveys, to address the science goals, a major flight objective was to acquire MABEL data over winter sea ice conditions.

Other targets of opportunity included coordinated land ice and sea ice flights with Operation IceBridge, flight lines that would be targeted by other NASA lidars (e.g., LVIS), ice caps in Iceland where other lidars have recently surveyed, and sites in Svalbard where colleagues deployed corner-cube retroreflectors for *in situ* comparison.

All datasets associated with *MABEL Iceland 2012* are available on the ICESat-2 website (<http://icesat.gsfc.nasa.gov/icesat2/data.php>).

## Acknowledgements

We thank the CPL instrument field team: Spencer Disque and Bill Hart. We thank the NASA Armstrong ER-2 pilots, Tim Williams and Stu Broce, and ER-2 Project Managers Tim Moes and Chris Jennison. We thank NASA Goddard Flight Center personnel David Hancock, Jeff Lee, Scott Luthcke, Charles Webb, and Kaitlin Walsh for data processing and analysis support.

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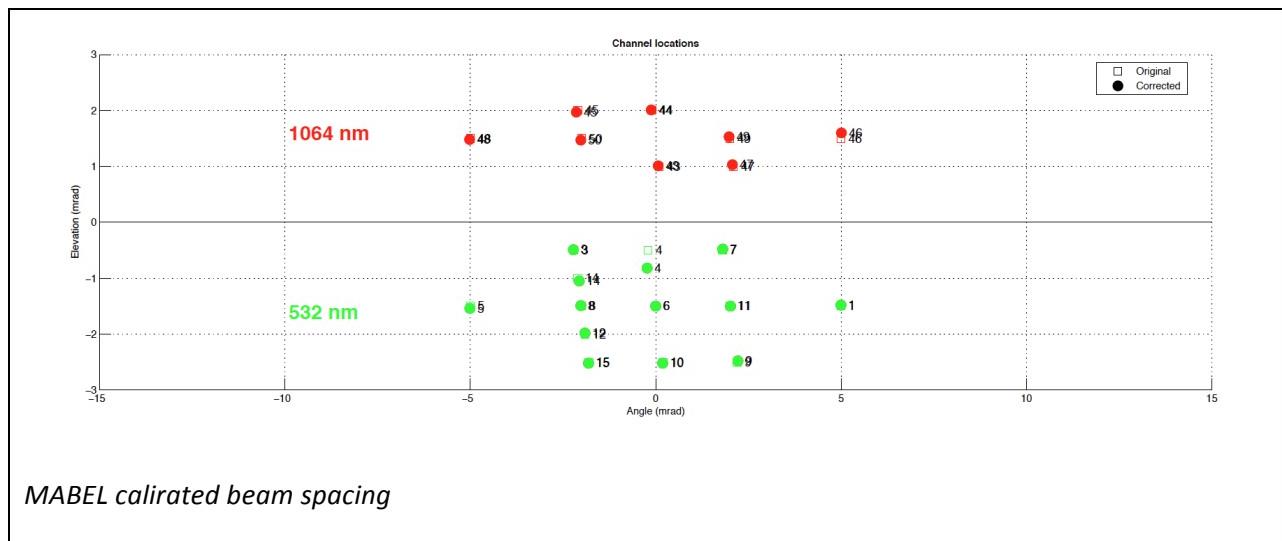
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## Appendix

The appendix of this document includes summaries associated with each individual mission flight. Details captured in these summaries include maps of flight tracks, comments about the instrumentation, and comments about weather. This document focuses on MABEL, as the primary instrument. As such, it includes flight summaries for all MABEL flights, including instrument check flights in California and transit flights to and from Iceland.

For the Iceland campaign, MABEL was configured with an etalon filter, to reduce solar background counts. All flights for the campaign were conducted during daylight. The repetition rate of MABEL for the Iceland 2012 campaign was 5 kHz.

For the Iceland 2012 campaign, instrumentation issues limited MABEL to 13 green beams and 4 near infrared beams with a maximum across-track beam spacing was 200 m. Many MABEL flights included pitch and roll maneuvers; the times of these are indicated in the individual flight summaries. The relative spacing of those beams, after calibrations based on pitch and roll maneuvers over the open ocean, is in the figure below.



03/27/2012

Mission: 'Dryden Checkout Flight'



Weather: High dense clouds throughout; very high data rates

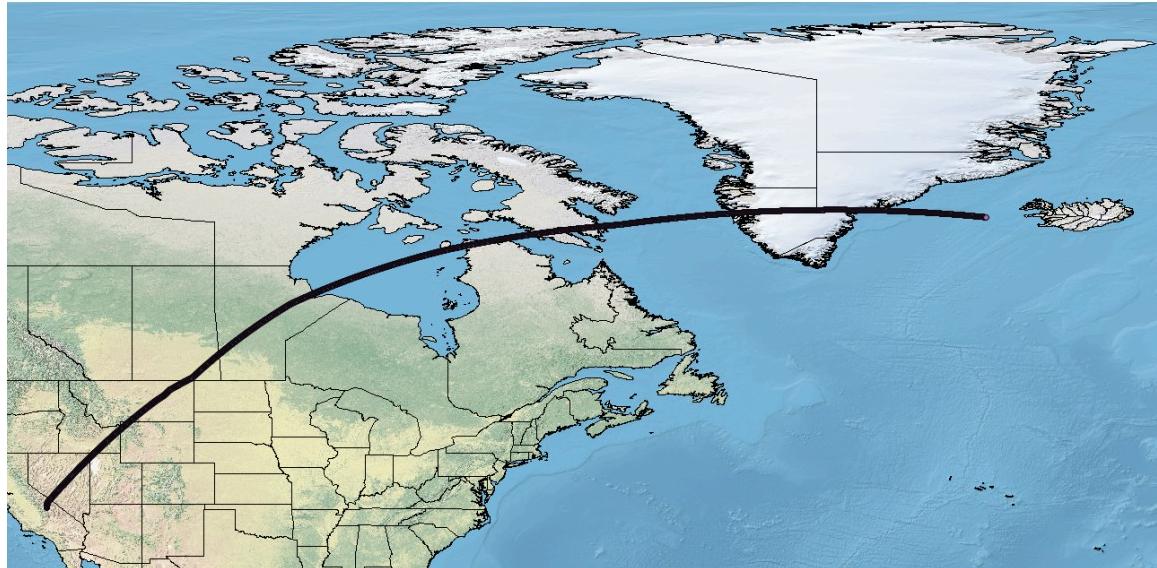
Comments: Also included: CPL

Points of interest:

Time (UTC)	Description
18:22:37	Laser status healthy
20:43:49	Laser off

04/02/2012

Mission: 'Transit to Iceland'



Weather: Clear over Montana, Hudson Bay, and S Greenland

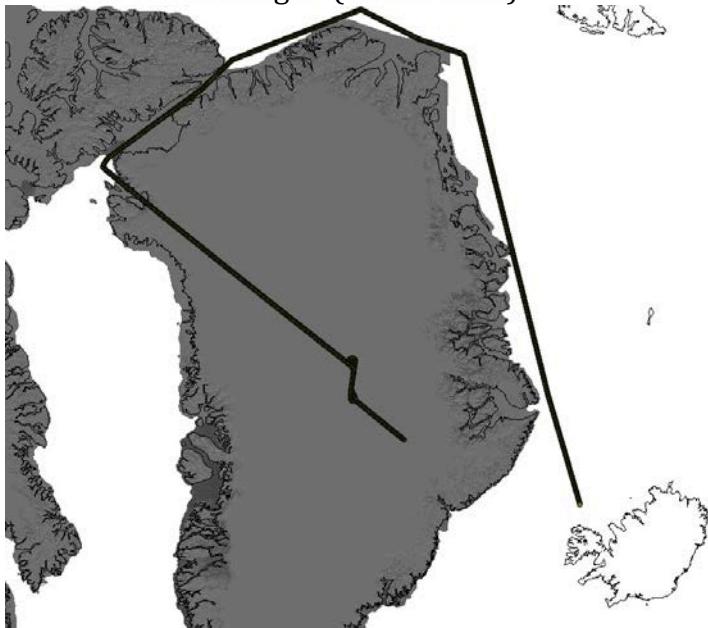
Comments: Also included: CPL

Points of interest:

Time (UTC)	Description
2:34:23	Laser status healthy
4:33:12	Start Fort Peck reservoir
4:36:20	End Fort Peck reservoir
6:24:2	Start Hudson Bay
7:40:53	End Hudson Bay
9:22:19	Start Greenland
10:11:34	End Greenland
10:52:37	Laser off

04/08/2012

Mission: 'Second Flight' (Nares Strait)



Weather: Clear over sea ice; Summit Camp reported clear skies

Comments: Also included: CPL, DCS; 3x passes over Summit Camp

- Bob Hawley's team GPS surveyed Summit the same day (4/8/12).
- Matches: ATM 4/2/12 flight; ATM 4/4/12; ATM 4/10/12

Points of interest:

Time (UTC)	Description
10:23:1	Laser status healthy
10:41:38	Start Summit Camp
11:20:15	End Summit Camp
13:1:11	Turn into Nares Strait
14:59:17	North end of sea-ice run
17:3:40	Laser off

04/10/2012

Mission: 'Operation IceBridge Overflight'



Weather: Clear over sea ice

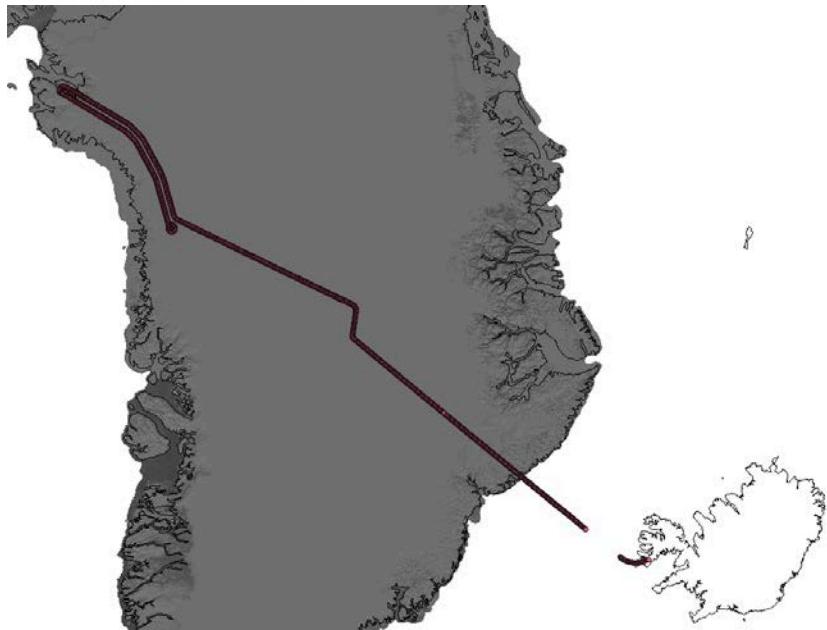
Comments: Also included: CPL, DCS. MABEL did not write to disk on northbound leg  
- Matches ATM 4/10/12

Points of interest:

Time (UTC)	Description
15:47:48	Laser status healthy
15:47:48	North end of sea-ice run
16:49:11	South end of sea-ice run
17:23:3	Laser off

04/12/2012

Mission: 'NW Glaciers'



Weather: Clear LVIS lines; Summit Camp reported ground fog

Comments: Also included: CPL, DCS. 2x passes of Summit Camp

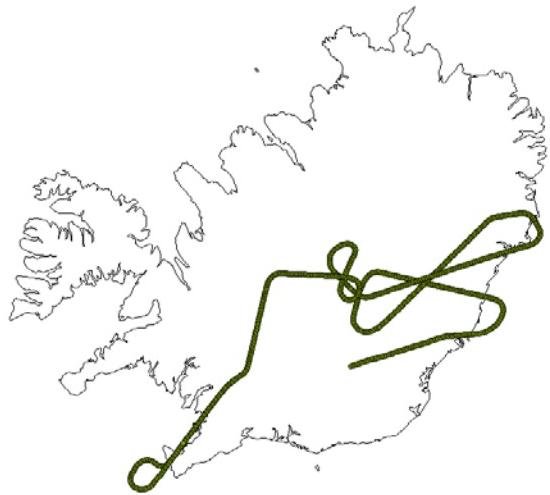
- Matches ATM 4/4/12; LVIS 5/1/12

Points of interest:

Time (UTC)	Description
10:45:59	Laser status healthy
11:46:58	Summit Camp 1
12:35:0	Start of LVIS run
15:17:6	End of LVIS run
15:57:2	Summit Camp 2
17:4:44	Laser off

04/15/2012

Mission: 'Iceland'



Weather: 15% cloud cover, including low stratus

Comments: Also included: CPL, DCS.

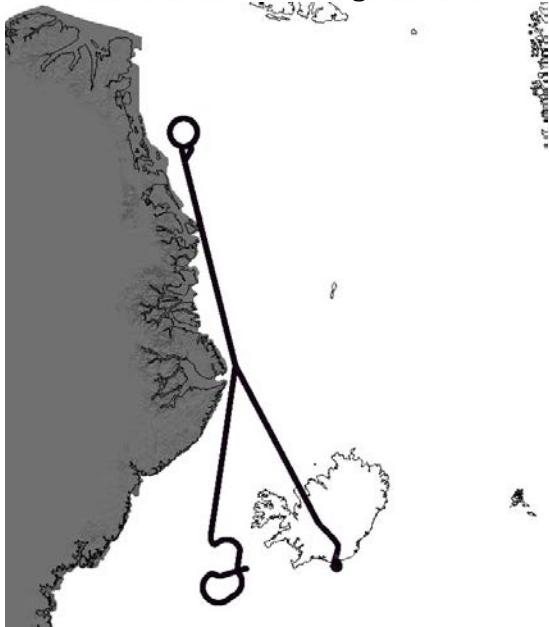
- John Anderson targets set near Hanger

Points of interest:

Time (UTC)	Description
8:40:40	Laser status healthy
10:13:54	Anderson targets 1
10:23:0	Anderson targets 2
10:24:7	Laser off

04/17/2012

Mission: 'Sea Ice and 5 degree 360s'



Weather: very little open ocean; slightly overcast in the north

Comments: Also included: CPL, DCS; sea ice 5 degree 360 and P&R maneuvers.

- Matches ATM 4/10/12

Points of interest:

Time (UTC)	Description
9:37:46	Laser status healthy
9:37:46	Attempt at an ocean 5 degree 360
11:19:11	South end of sea-ice run
12:00:30	Start of P&R maneuvers
12:09:00	End of P&R maneuvers
12:24:1	Start of sea ice 5 degree 360
12:51:37	End of sea ice 5 degree 360
13:57:21	South end of sea-ice run
10:24:7	Laser off

04/19/2012

Mission: 'Jakobshavn 1'



Weather: clouds on eastern N/S transects, then clear throughout

Comments: Also included: CPL, DCS. Ian Howat at J4 on 4/21; 3x passes of his J2

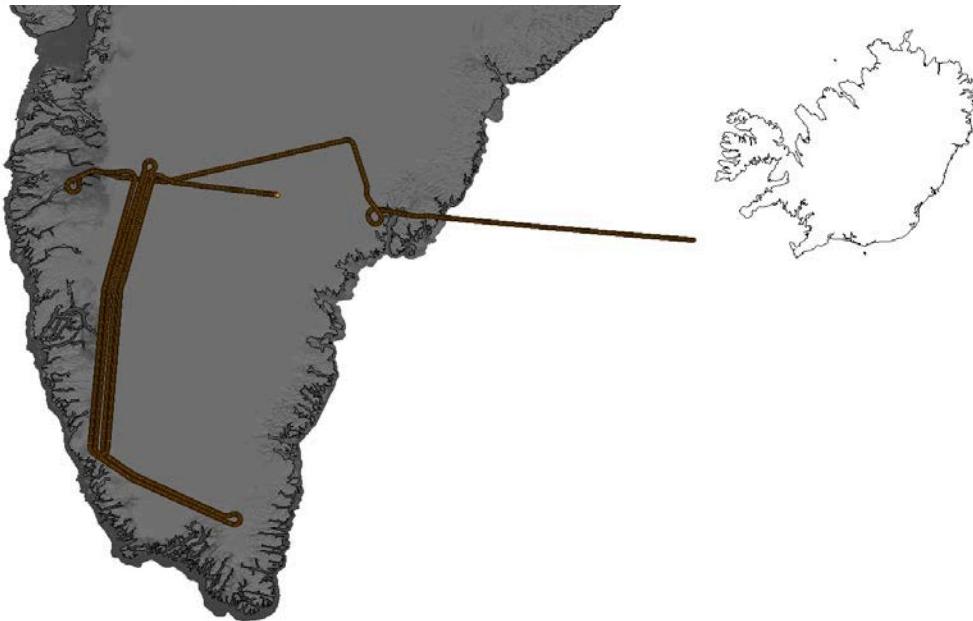
- Matches ATM 4/29/12
- Crosses ATM 4/21/12; ATM 5/2/12

Points of interest:

Time (UTC)	Description
7:49:1	Laser status healthy
8:40:59	Start Jakobshavn run
8:54:38	J2 1
9:22:21	J2 2
13:19:59	J2 3
13:24:44	Closest to J4
13:24:44	End Jakobshavn run
14:21:10	Laser off

04/20/2012

Mission: 'SW Coast 1'



Weather: Generally clear

Comments: Also included: CPL, DCS. Mike MacFerrin on ground (4/28-5/5).

- Matches ATM 4/20/12

Points of interest:

Time (UTC)	Description
9:22:26	Laser status healthy
10:6:7	Start Helheim run
10:29:10	End Helheim run
10:55:58	MacFerrin 1
11:9:13	Kanger DEM 1
11:17:13	Kanger DEM 2
11:25:48	Start of ATM lines
12:7:40	Start OIB S
12:52:16	End OIB N
13:40:24	Start OIB NW
14:20:33	End OIB NW
14:23:29	Start OIB NE
15:2:12	End OIB NE
15:2:12	End ATM lines
15:6:3	MacFerrin 2
15:21:43	Laser off

04/21/2012

Mission: 'Jakobshavn 2'



Weather: Generally clear; building haze to the east

Comments: GPS FAILS; Also included: CPL, DCS. Ian Howat at J4 on 4/21

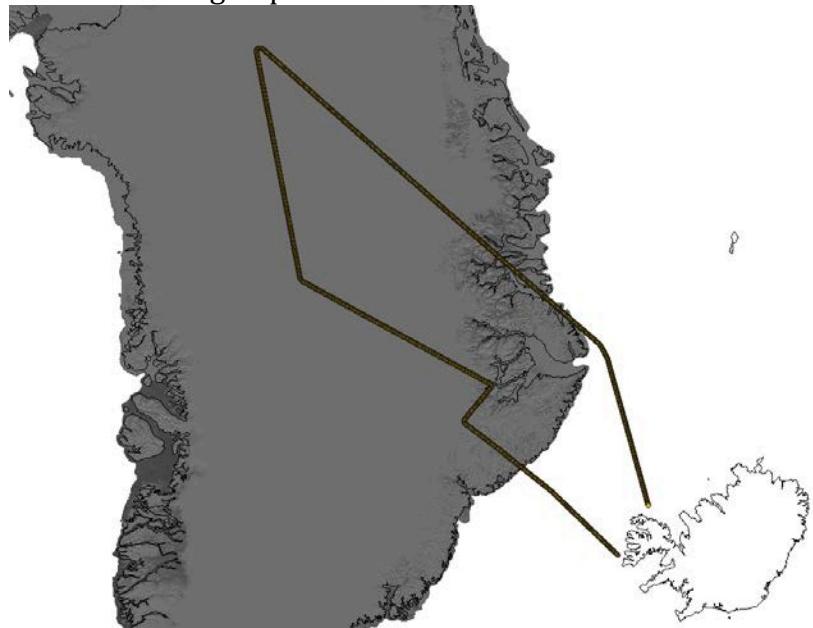
- Matches ATM 4/29/12
- Crosses ATM 4/21/12; ATM 5/2/12

Points of interest:

Time (UTC)	Description
12:23:13	Laser status healthy
12:43:58	Howat's J4
12:51:39	Howat's J1
13:0:39	Calving front
13:15:31	Start ATM lines
14:51:41	GPS fails

04/23/2012

Mission: 'Salvage Operation'



Weather: Generally clear

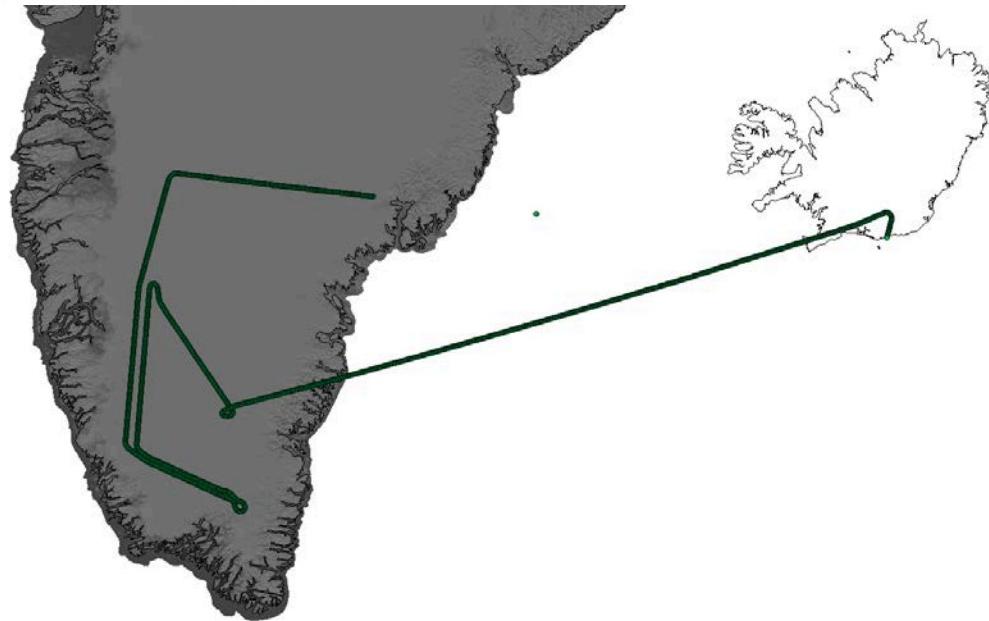
Comments: Also included: CPL, DCS. Ian Howat at J4 on 4/21  
- Matches ATM 3/30/12

Points of interest:

Time (UTC)	Description
9:26:14	Laser status healthy
10:8:42	Start Vestfjord line
10:17:0	End Vestfjord line
11:3:49	Start CryoSat/ATM line
11:51:20	End CryoSat/ATM line
14:4:1	Laser off

04/24/2012

Mission: 'SW Coast 2'



Weather: Generally clear; overcast over MacFerrin; broken on western ATM line

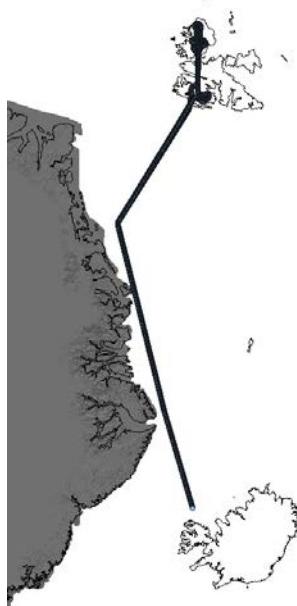
Comments: Also included: CPL, DCS.

Points of interest:

Time (UTC)	Description
10:10:45	Laser status healthy
10:42:0	Start ATM lines
12:23:19	End ATM lines
12:50:13	South Dome AWS
14:32:15	E15 (cloudy)
14:33:34	Laser off

04/25/2012

Mission: 'Svalbard'



Weather: Generally clear; pilot altered course on ETON line to avoid clouds

Comments: Also included: CPL, DCS.

- Jack Kohler at western targets; Thorben Dunse at eastern targets.

Points of interest:

Time (UTC)	Description
9:59:46	Laser status healthy
11:49:33	Enter Kongsvegen area
13:52:55	Exit Kongsvegen area
16:18:1	Laser off

04/27/2012

Mission: 'Transit from Iceland'



Weather: Cloudy over S Greenland; intermittently cloudy over Wisconsin

Comments: Also included: CPL and DCS

Points of interest:

Time (UTC)	Description
11:20:38	Laser status healthy
16:30:53	Start Wisconsin stretch
16:48:47	End Wisconsin stretch
16:48:47	Laser off



